CMS data analysis - Hands on

Jelena Mijušković

University of Montenegro and IRFU, CEA, University Paris Saclay

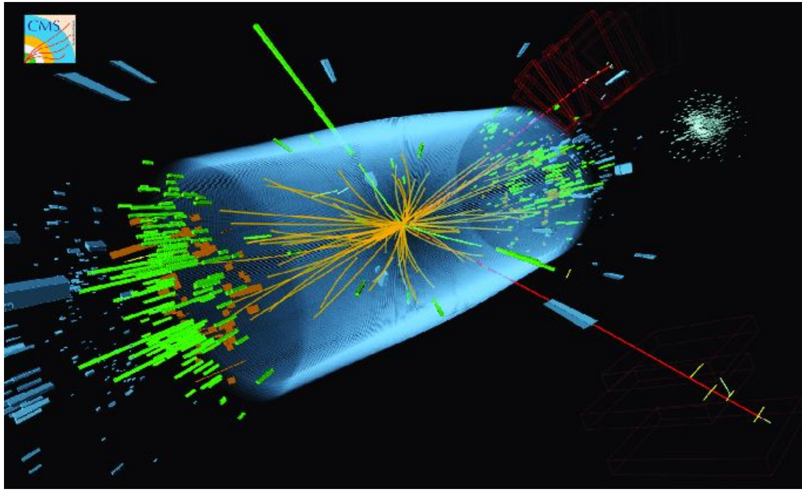
Sarajevo School of High Energy Physics
October 2022

Introduction

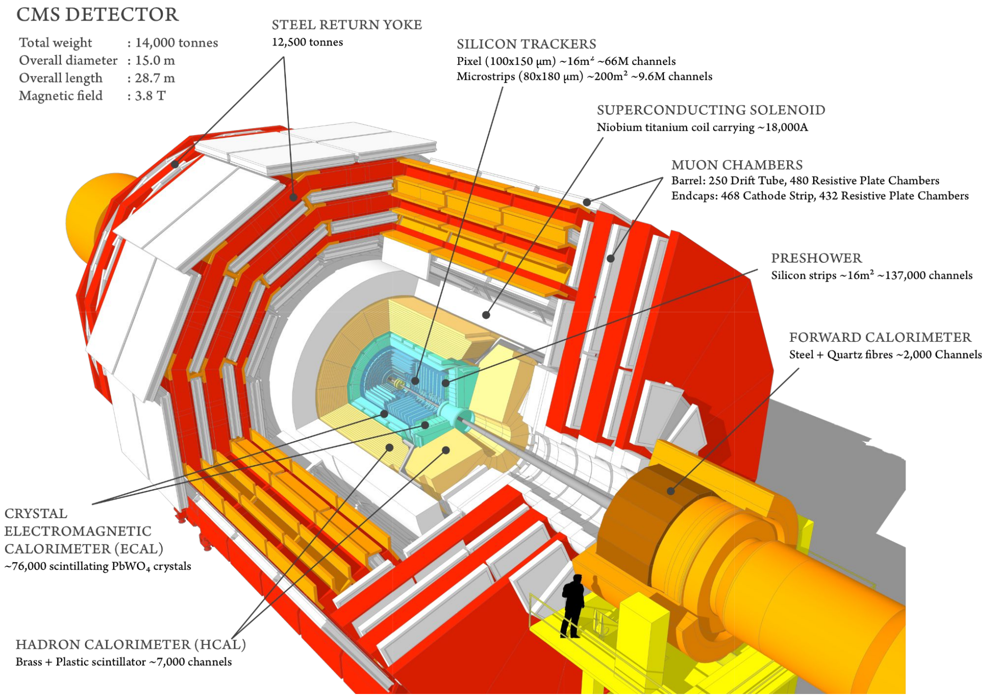
- Many interesting lectures on physics and instrumentation given at SSHEP

- The hands on session will give you an insight on how data analysis is performed

- Open data from CMS experiment will be used in the hands on sessions



Compact Muon Solenoid (CMS)



Location	Cessy, France
Size	21 m long, 15 high m and 15 m wide

Main requirements for CMS design:

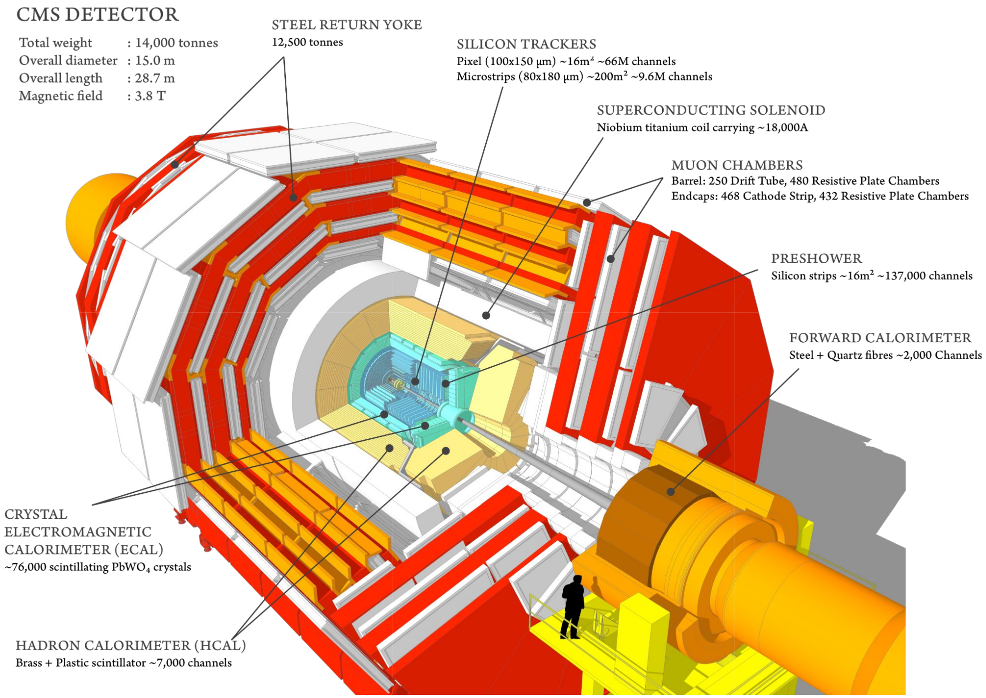
→ high performance system to detect and measure muons

→ high resolution method to detect and measure electrons and photons

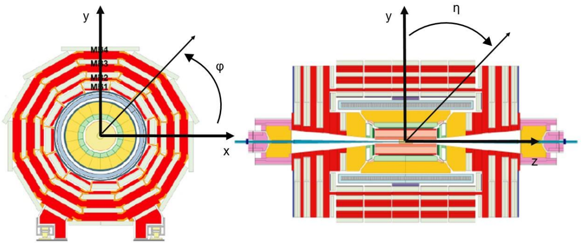
→ high quality central tracking system to give accurate momentum measurements

→ “hermetic” hadron calorimeter to prevent particles from escaping detection

CMS - coordinate system



➢ Cylindrical coordinate system with origin at the interaction point



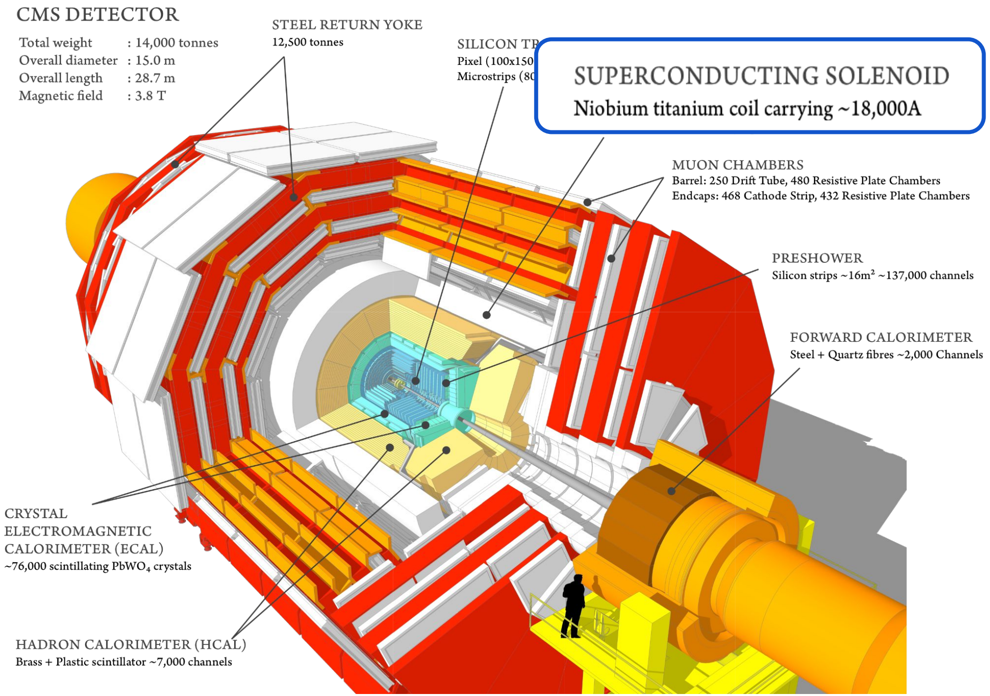
➢ The angular distribution of particles - rapidity

$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right) \xrightarrow{p \gg m} \eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

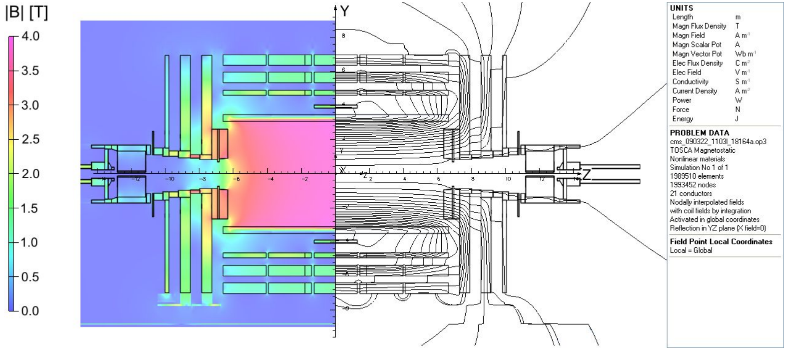
➢ The angular distance between particles:

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

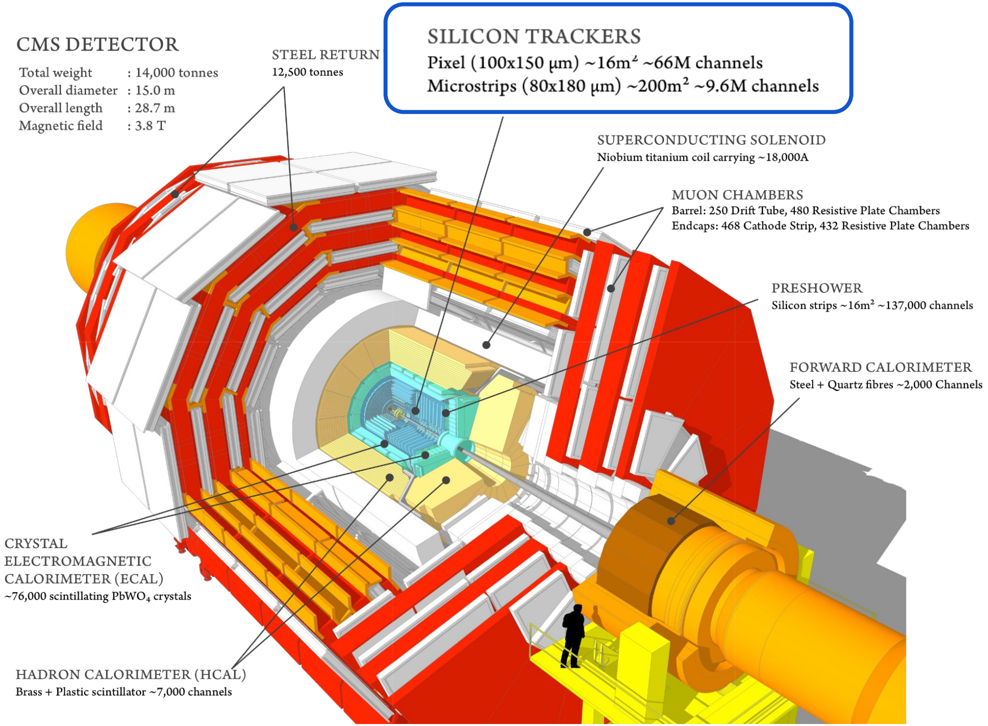
CMS - Solenoid



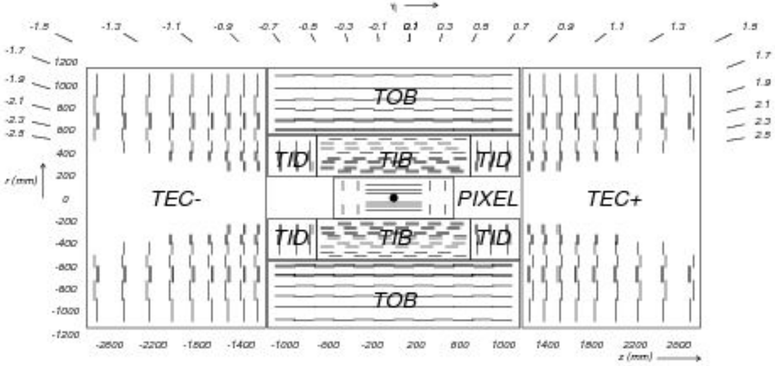
- ➢ Provides a magnetic field of 3.8 T
- ➢ Steel return yoke guides a magnetic field of 1.8 T in the region outside of the magnet



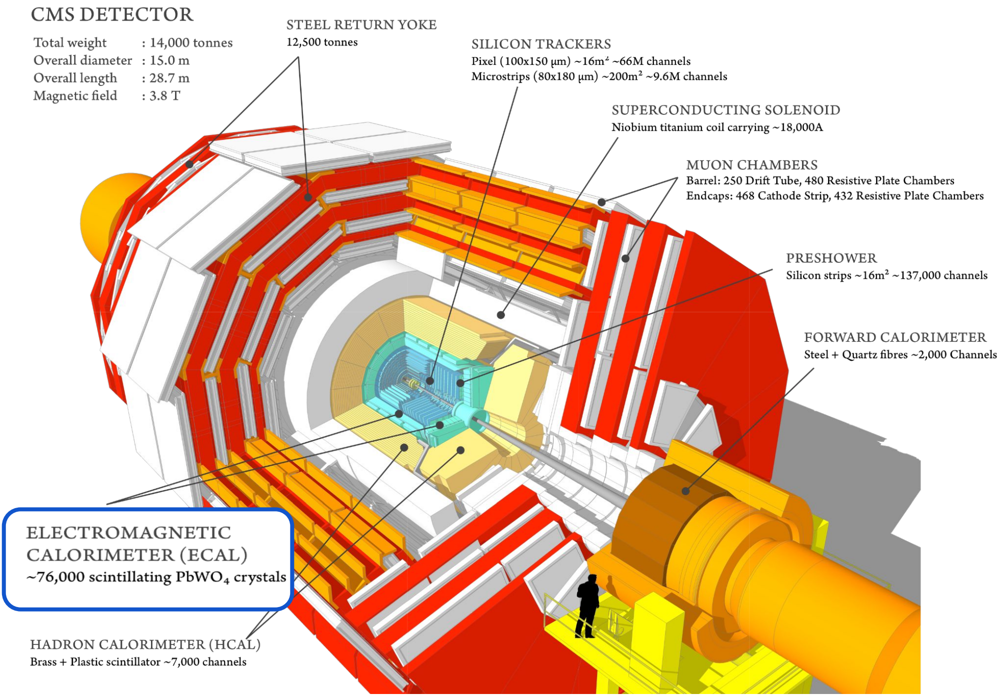
CMS - Tracker system



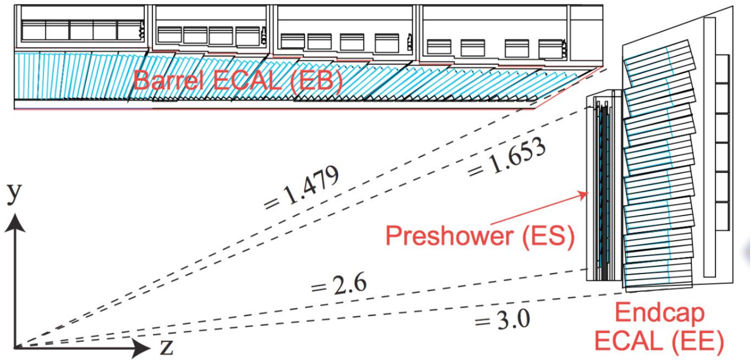
- ➢ **Momentum resolution**, for muons with the high p_T (100 GeV) in the central region, is about **2%**
- ➢ **Impact parameter resolution** achieved by the inner tracker is about **15 μm**



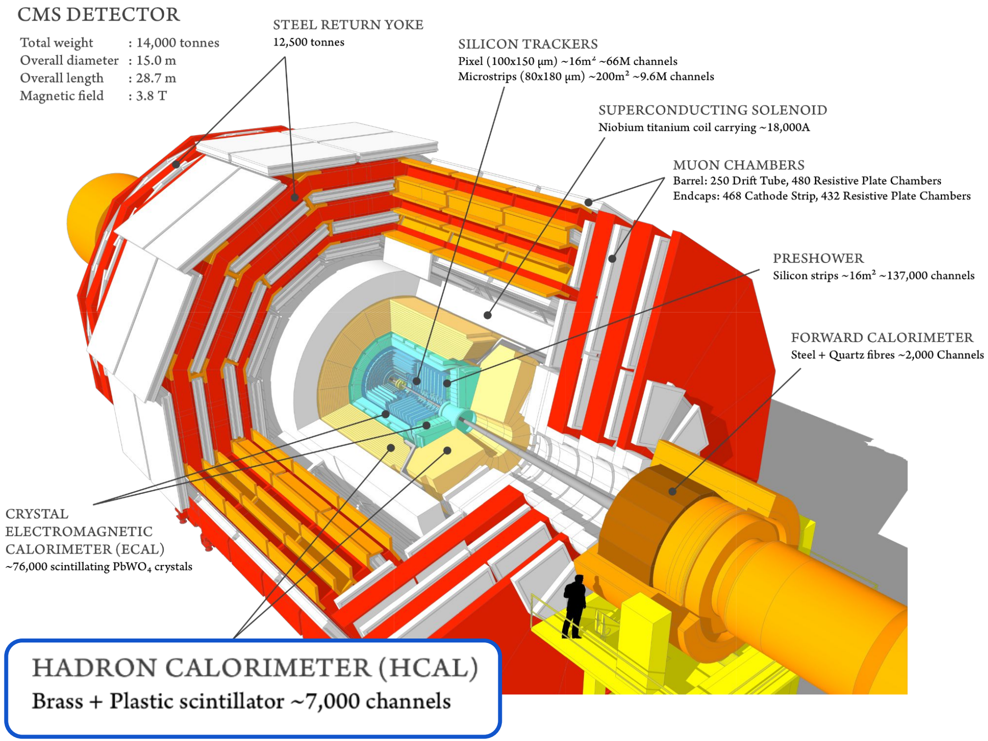
CMS - Electromagnetic calorimeter (ECAL)



➢ Design performance of the ECAL - **energy resolution of 1%** for photons from a H → γγ decay

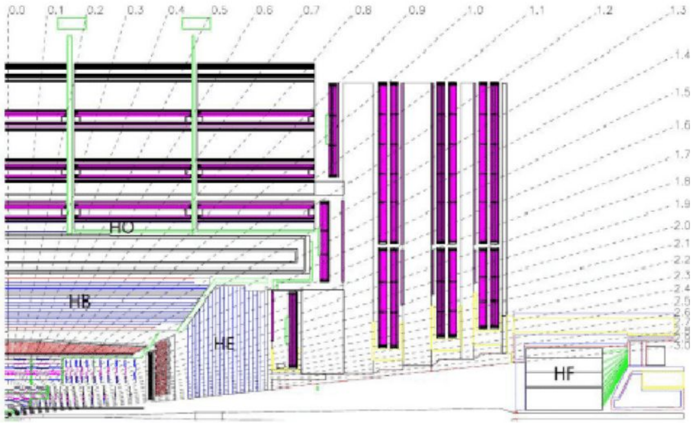


CMS - Hadronic calorimeter (HCAL)

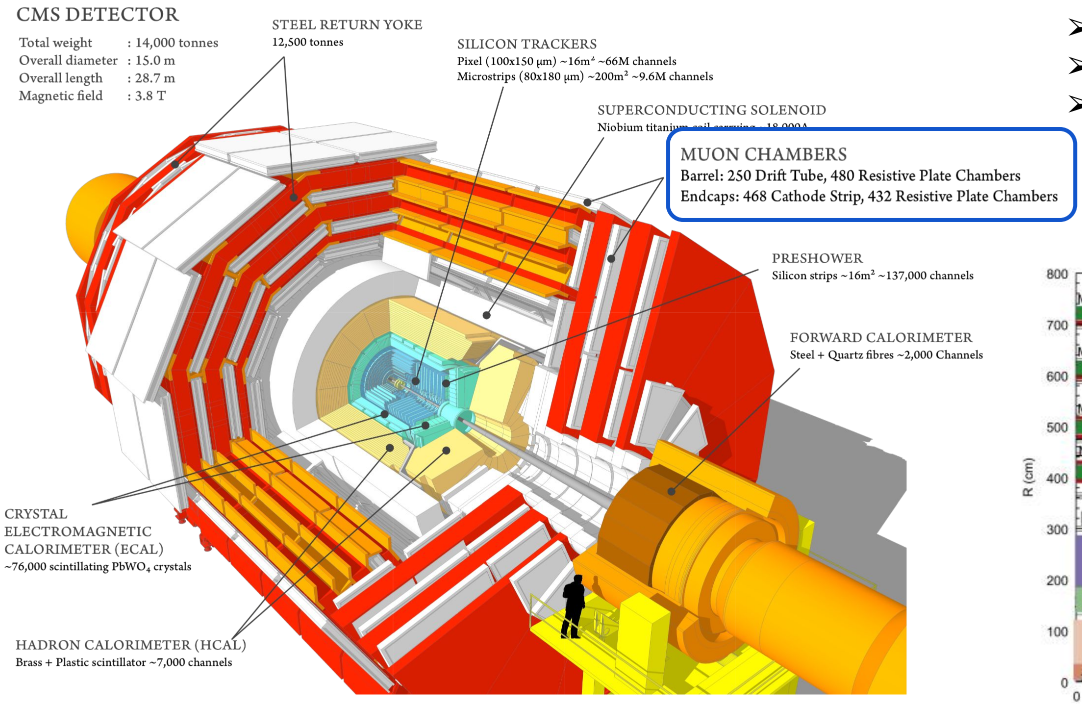


➢ The energy resolution of HCAL + ECAL

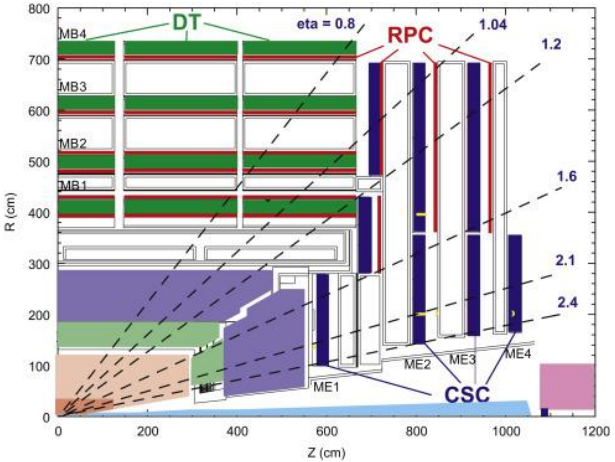
$$\frac{\Delta E}{E} = \frac{84.7\%}{\sqrt{E}} \oplus 7.4\%$$



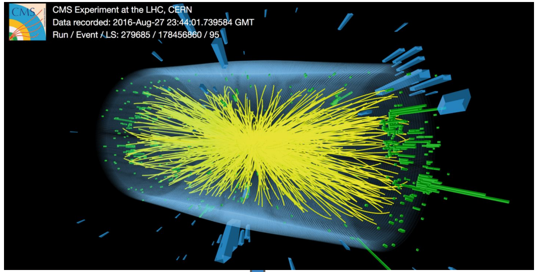
CMS - Muon system

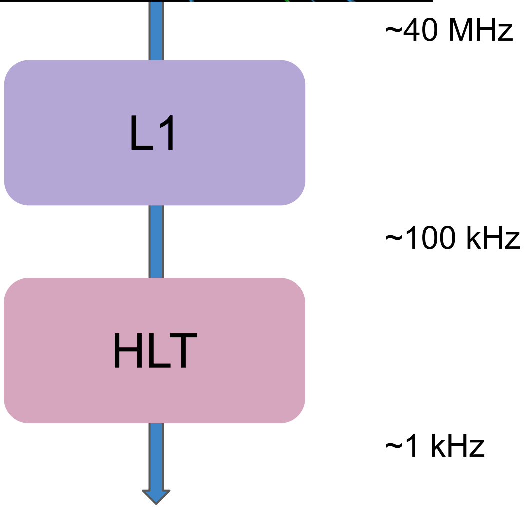


- Spatial resolution Drift Tubes: 80 - 120 μm
- Spatial resolution Chatode Stips: 30 - 150 μm
- Time resolution Resistive Plate Chambers ~3 ns



CMS - Trigger system





Data storage and full reconstruction

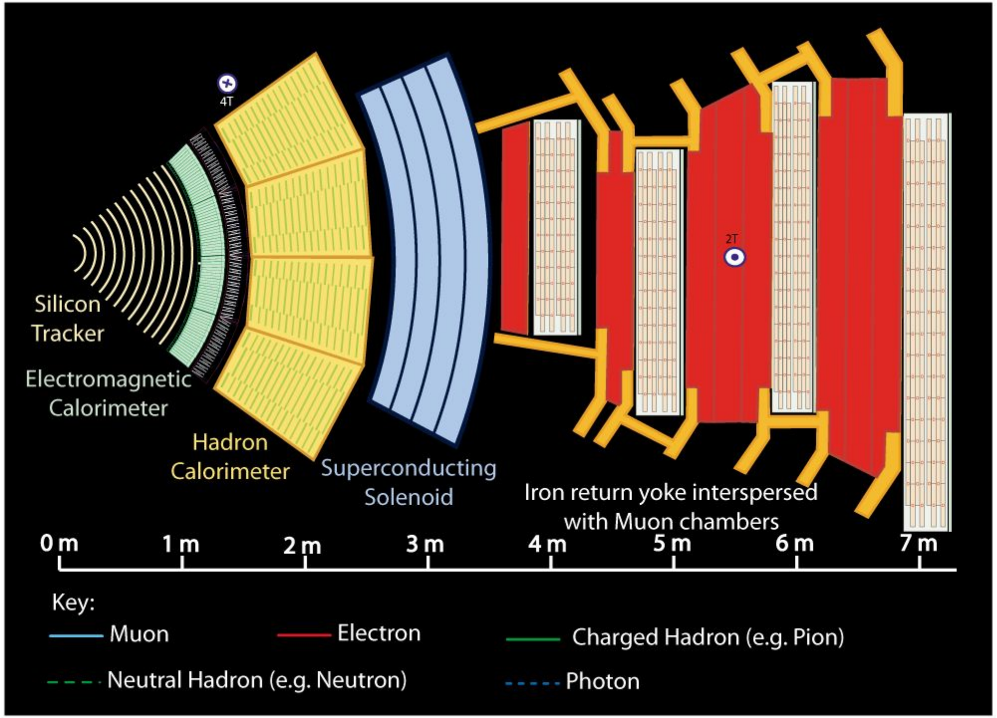
- The LHC produces close to 40 million collisions each second
- Trigger system was developed to keep only events of interest

- The CMS trigger works in two stages:

1. **Level-1 (L1) trigger**
   → operates at the hardware level and involves the calorimeters and the muon system

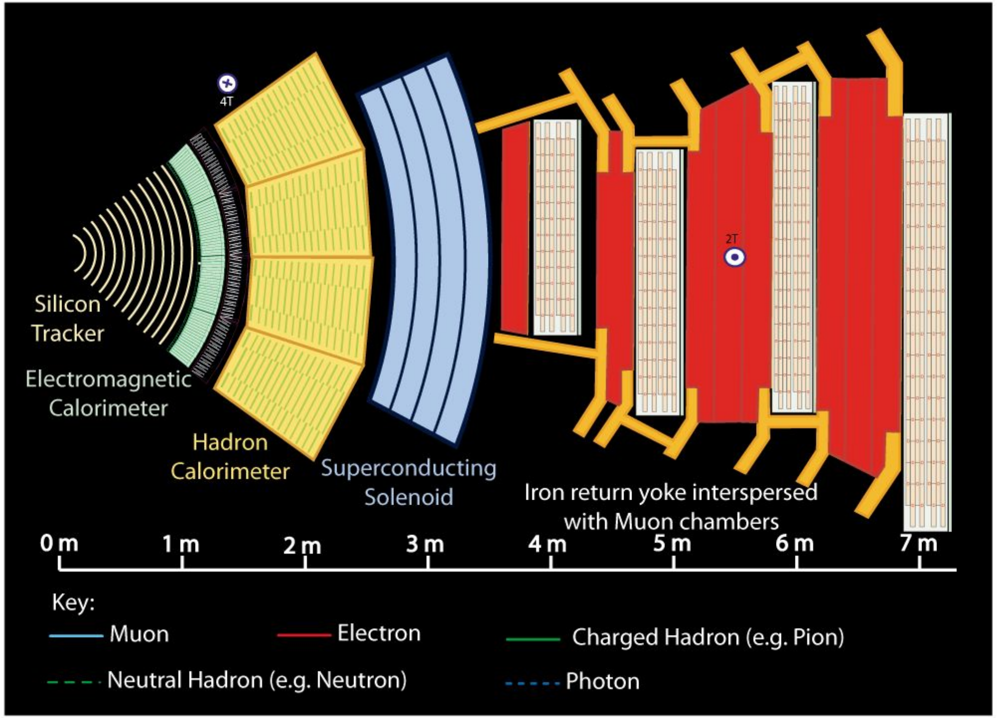
2. **High-Level trigger (HLT)**
   → based on the software used for the standard event reconstruction, with optimized configuration

Particle flow algorithm



- The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

Particle flow algorithm

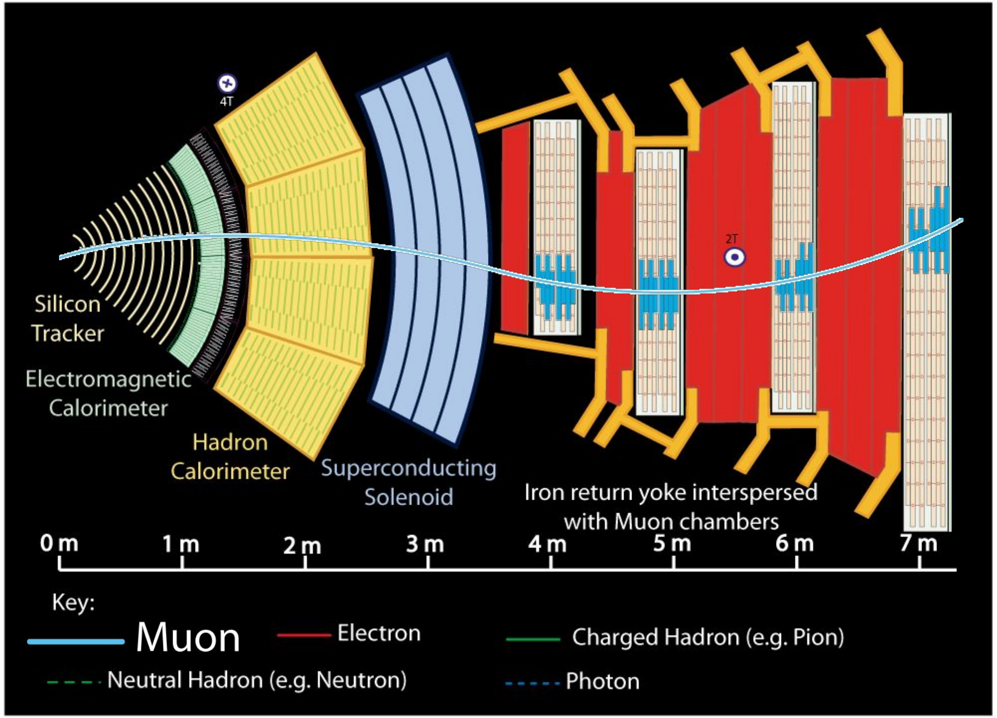


- ➢ The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- ➢ Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

Time for hands on!

https://github.com/JMijuskovic/HandsOn_SSHEP2022

Particle flow algorithm

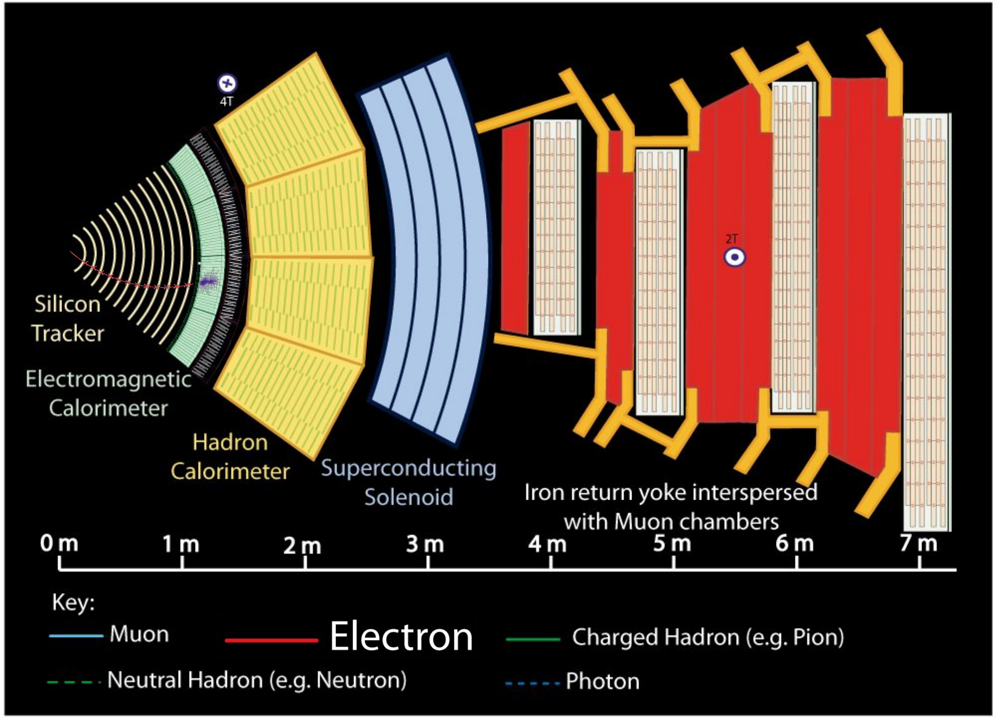


- ➢ The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- ➢ Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

muon - hits in the tracker and muon system

- **stand-alone muons** - reconstructed using the information from muon chambers only
- **tracker muons** - reconstructed in the tracker, where the track is compatible with at least one track segment in one of the muon detectors
- **global muons** - the track from the inner tracker is compatible with the one in the muon chambers.

Particle flow algorithm

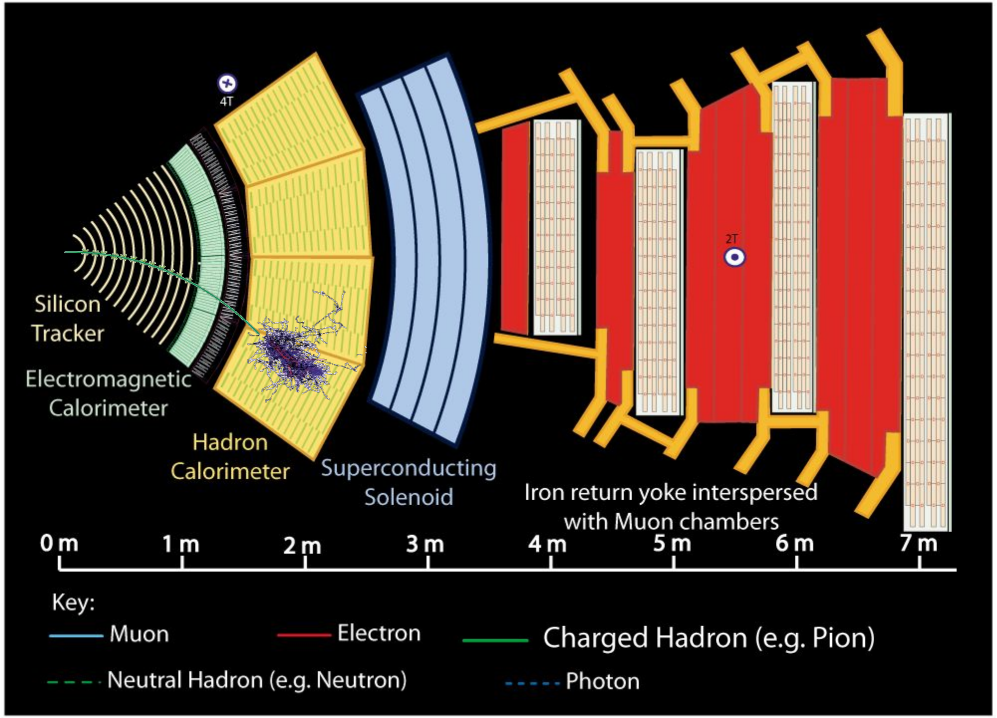


- ➢ The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- ➢ Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

muon - hits in the tracker and muon system

electron - hits in the tracker and an electromagnetic shower in the ECAL

Particle flow algorithm



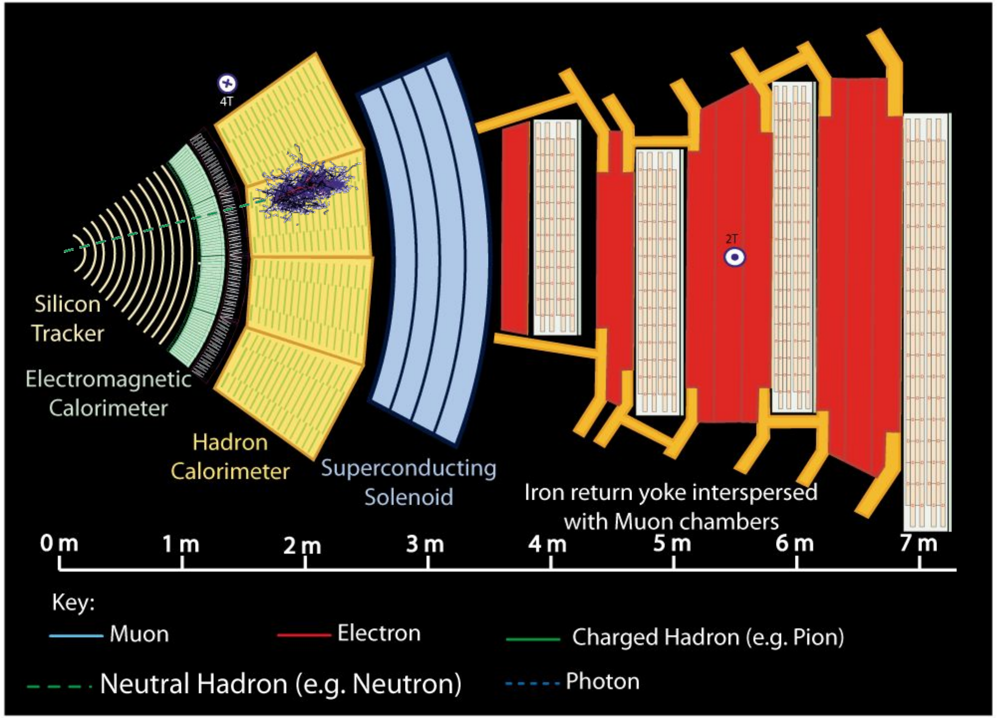
- ➢ The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- ➢ Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

muon - hits in the tracker and muon system

electron - hits in the tracker and an electromagnetic shower in the ECAL

charged hadron - hits in the tracker and energy deposits in the HCAL

Particle flow algorithm



- The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

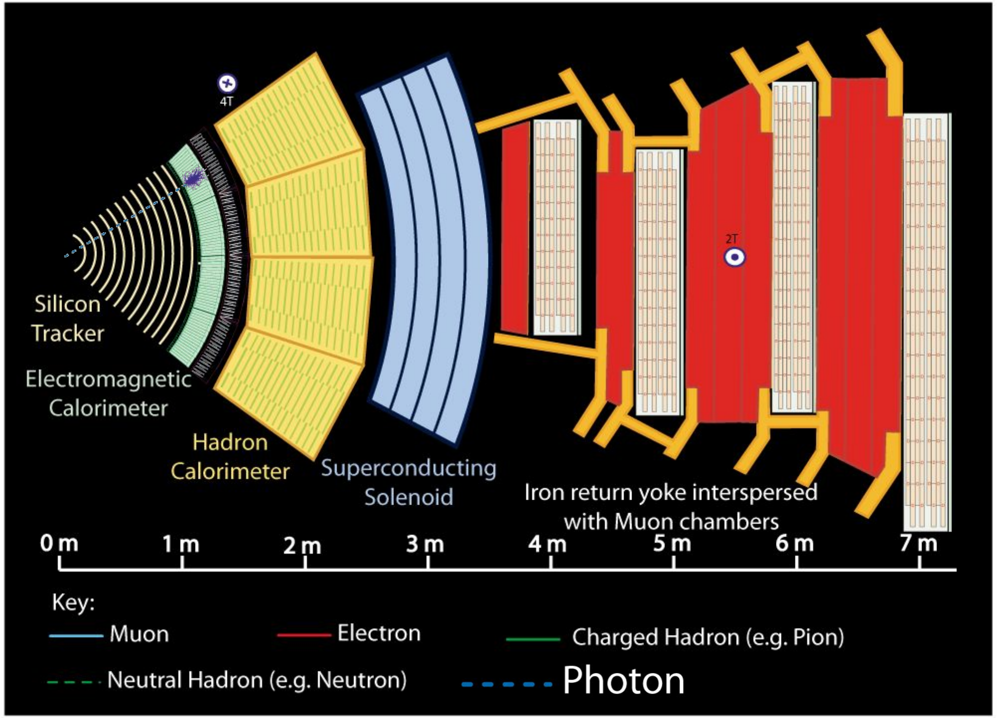
muon - hits in the tracker and muon system

electron - hits in the tracker and an electromagnetic shower in the ECAL

charged hadron - hits in the tracker and energy deposits in the HCAL

neutral hadron - energy deposits in the ECAL and HCAL

Particle flow algorithm



- The reconstruction of particles in the CMS experiment is based on the **Particle Flow (PF) algorithm**
- Information from the subdetector systems are collected and combined to infer the nature of the particles in the event and reconstruct them

muon - hits in the tracker and muon system

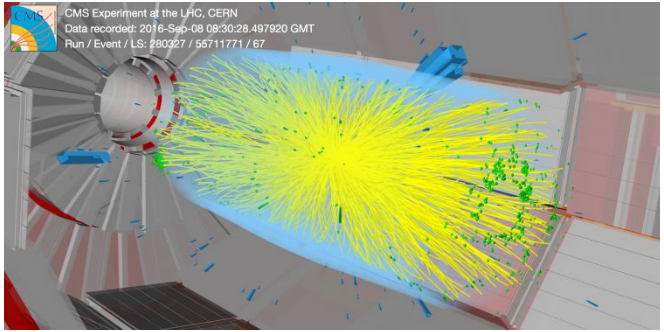
electron - hits in the tracker and an electromagnetic shower in the ECAL

charged hadron - hits in the tracker and energy deposits in the HCAL

neutral hadron - energy deposits in the ECAL and HCAL

photon - electromagnetic shower in the ECAL

Pileup effect

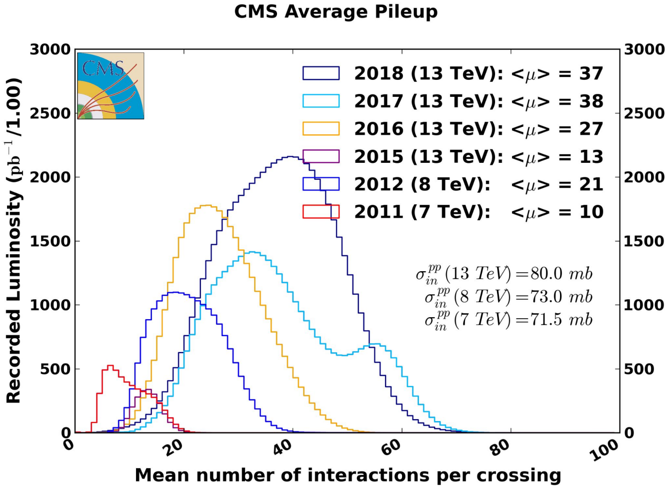


- At the LHC large bunches of protons are collided, such that multiple protons interact when the bunches collide in CMS

- Besides of particles from the interaction of interest, particles from multiple additional interactions are recorded

- The effect of overlapping between the main interaction and interactions that are not coming from the hard scattering is called **pileup**

- Proton bunches are separated by 25 ns and the response of the detector is not instantaneous - overlapping interactions coming from different bunch crossings - **out-of-time pileup**



BACK UP

Large Hadron Collider (LHC)

- The LHC is a circular accelerator designed to collide protons or heavy ions
- Located at the border between France and Switzerland, close to Geneva

Parameter	Nominal value
Circumference	26 659 m
Dipole operating temperature	1.9 K (-271.3 ºC)
Number of magnets	9593
Peak magnetic dipole field	8.3 T
Energy, protons	7 TeV
Bunch separation	25 ns
Number of bunches	2808
Number of protons per bunches	$1.15 \cdot 10^{11}$
Revolution frequency	11245 Hz